The Effects of Thin, Near-surface Layers on Seismic Signals

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ABSTRACT

Signals generated by moving tracked vehicles can be significantly affected by near-surface materials including pavements, compacted soils, shallow bed rock, and the water table. The ways that seismic signals depend on these surface layers are examined by analyzing impulsive point forces applied at the earth-air interface. Fields are calculated using a plane layered frequency domain wavenumber model. Synthetic time domain seismograms are generated by convolving the layered earth impulse responses over a band of frequencies with an appropriate source force function. The effect of constant Q attenuation is also included. Our results are related to seismic signals from tracked vehicles by noting that the spatially distributed nature of the track-ground forcing at any instant in time, can be obtained by superposition of multiple point source results. In generating earth impulse responses, we use surface layering that is commonly encountered moving vehicle problems. In each layer case considered, we systematically vary layer thickness to demonstrate how thick a particular layer must be to generate a significant alteration in the character of the seismic signals. It is found that surface layers less than about a meter thick do not have a major effect on observed waveforms in the frequency bands of interest. However, for near surface layers greater than 1.5 m, comparisons between high velocity and low velocity materials can have amplitude differences as great as 20 dB at ranges of 100 m. Waveforms from these two models also have substantively different surface waves modal characteristics.

1. INTRODUCTION

The seismic signals recorded from moving vehicles can be used to track, and identify them. However, for seismic signals to achieve their full potential in fieldable battlefield systems, the wide variety of geologic effects on signal properties must be considered. The upper 10 m of the geologic materials can have a particularly pronounced effect on propagating seismic surface waves. The effects include large variations in signal amplitude, and waveform dispersion. The character of the recorded surface wave signals can be thought of as a convolution of the force the vehicle applies to the earth and the response of the earth to the forcing. In this paper we systematically apply a layered media seismic propagation model to several common geologic scenarios and analyze the effects of layer properties on the seismic waveforms.

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2. METHOD

Seismograms are computed in two steps. First at a number of frequencies, the Green's Function is calculated for the response of a point source in an infinite media by using a wavenumber integration method. The geometry of this calculation is shown in Figure 1. The force time function of the source is then transformed into the frequency domain. Next, the Green's Function and the transform of the time force function are multiplied together in the frequency domain (this gives a convolution in the time domain). Finally, the result is transformed back to the time domain to generate seismogram waveforms.

The most difficult part of the computation is generating the frequency domain Green's Function. This is done using the program GRPOINT (Hisada, 1994; Hisada, 1995a; Hisada, 1995b). This program gives the response for directed point forces at arbitrary depth in a layered media; the depth of the receiver is also arbitrary. Both vertical and horizontal directed point forces are allowed. All three components of the ground motion are calculated. A program was developed to take the output of GRPOINT put in a number of different force time functions, and compute seismograms.

In this paper, unless indicated, all results are for a vertical point force source (TX) at the surface with a receiver (RX) on the surface. The seismogram give the vertical velocity of ground particles. This is analogous to the signals recorded by vertical geophone. The results are denoted as wavenumber integration (WI) results. The force time function of the vertical point force is shown in Figure 2.

3. RESULTS

To verify the WI calculation a comparison was made with time domain finite difference (TDFD) method results obtained with the PTOP program (Ketcham et al, 2000; Hestholm and Ruud, 1998). The results , shown in Figure 3, show the two methods give very similar waveforms, and thus both are giving accurate results.

The seismograms for the model L2, shown in Figure 4, are typical for a low velocity over a halfspace. The major arrival is a dispersed fundamental Rayleigh wave arrival. The seismograms for the model L1, shown in Figure 5. In this model the near surface layer has a very large s-wave velocity contrast with the half space, which introduces a scalloped appearance in the waveforms. This is attributed to the interference of the fundamental Rayleigh wave mode with a higher order Rayleigh wave mode. The result sharply contrasts with the much simpler waveforms seen in the L2 model.

The next model, H1, has a high velocity layer at the surface; waveforms are shown in Figure 6. Such a model could represent a frozen layer above unconsolidated soil. The waveform for H1 show two distinct frequency bands. We hypothesize that the early, high frequency arrival is energy that has traveled in the layer, while the later low frequency wave is the fundamental Rayleigh wave in the whole layered system.

Figure 7 gives a comparison of the amplitudes versus distance for the three models. The L2 model has the highest amplitudes, the L1 model is next; the H1 model gives the smallest amplitudes. At a range of 110 m the L2 model amplitude is about 20 dB above the H1.

Using the low velocity, L1, geologic model we explore the effect of layer thickness. The results are shown in Figure 8. For H = 0 there is no low velocity layer and a simple Rayleigh wave pulse on the surface of a high velocity material halfspace is observed at about .1 s. The effect of the layer does not alter the waveform significantly until H approaches 1 m. Beyond this thickness, a slower arrival starts to appear. This is energy that is traveling in the layer as a leaky guided mode. The scalloped waveforms are observed from interfering Rayleigh modes are observed for 1 m < H < 8 m. At H = 8 m, the high speed early arrival is very weak compared to the Rayleigh wave arrival. Finally for an infinitely thick layer (H = ∞) a simple Rayleigh wave arrival is seen.

Using the H1 model, the effect of high velocity layer thickness on waveforms is shown in Figure 9. For H = 0 there is no high velocity layer and a simple Rayleigh wave pulse on the surface of a low velocity material halfspace is observed at about .34 s. The effect of the layer does not alter the waveform significantly until H approaches 0.75 m. At thickness larger then this, a higher velocity arrival begins to appear. This is energy that is traveling in the layer. The waveform for H = 1 m, shows the early higher velocity, high frequency, arrival and the later lower velocity arrival. Finally for an infinitely thick layer (H = ∞) a simple Rayleigh wave arrival, for the high velocity material, is seen.

4. CONCLUSIONS

We have compared our wavenumber integration results with ERDC-CRREL's finite-difference models and demonstrated excellent amplitude, arrival time and frequency content agreement. This demonstrates that both methods are cable of generating correct results. In general, our systematic analysis of simple layered models shows that strong velocity variations of near surface layers will not effect signal characteristics until the layer thickness exceeds 1 m. This is particularly true of high velocity materials. Low velocity geologic materials overlaying high velocity materials have the greatest impact on signal properties by supporting multiple high amplitude Raleigh wave modes. In this case, waveforms show extended (in time) group envelopes with complicated internal interference characteristics. Lastly we note that at ranges of 110 m the signal amplitudes can differ by as much as 20 dB between low velocity layers and high velocity layers.

5. REFERENCES

Hestholm, S., and B. Ruud, 1998, 3-d finite-difference elastic wave modeling including surface topography: Geophysics, 63, 613-622.

Hisada, Y., 1994, An efficient method for computing Green's Functions for a layered half-space with sources and receivers at close depths: BSSA, 84, 1456-1472.

Hisada, Y., 1995a, An efficient method for computing Green's Functions for a layered half-space with sources and receivers at close depths (Part2): BSSA, 84, 1456-1472.

Hisada, Y., 1995b, Reply to Comment on: An efficient method for computing Green's Functions for a layered half-space with sources and receivers at close depths by Y. Hisada by Roy J. Greenfield: BSSA, 84, 1456-1472.

Ketcham, S. A., M. L. Moran, and R. J. Greenfield, 2000, The effect of a topographic depression on guided seismic surface waves: SEG International Exposition, Calgary, Alberta, Canada, Aug. 6-11, 2000, 2213-2216.

6. ACKNOWLEDGEMENTS

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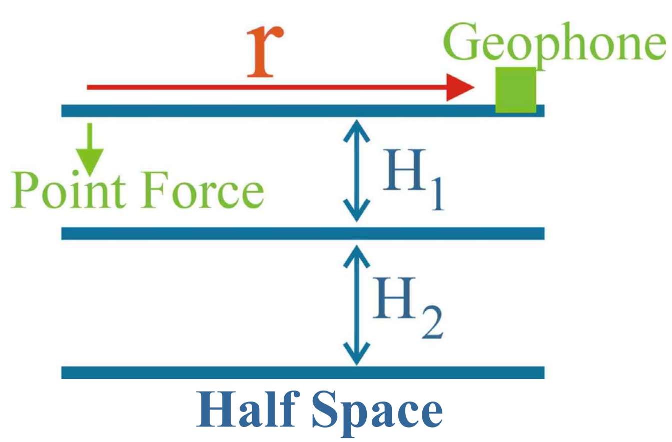

Figure 1. Geometry for point source in a layered medium. Force can be in arbitrary direction. r is the range to the RX.

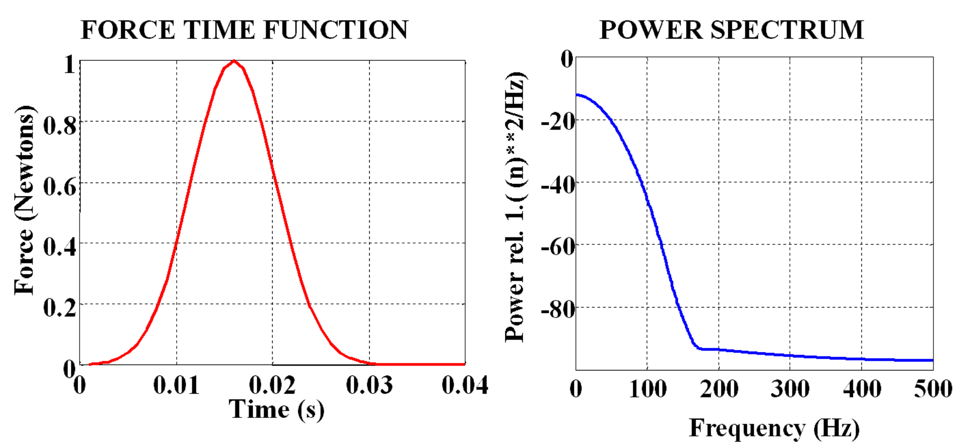

Figure 2. Force time function and it's power spectra.

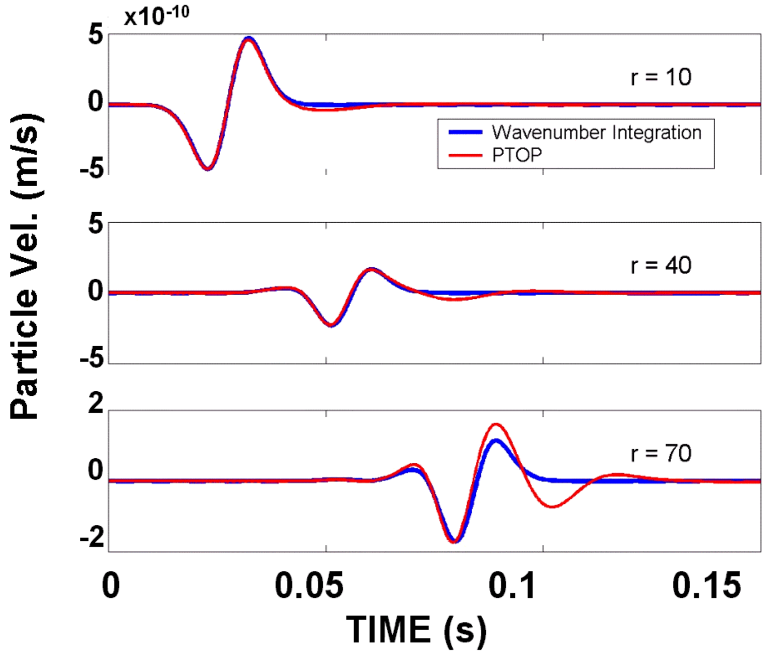

Figure 3. Comparison of waveforms from PTOP (FDTD) and wavenumber integration.

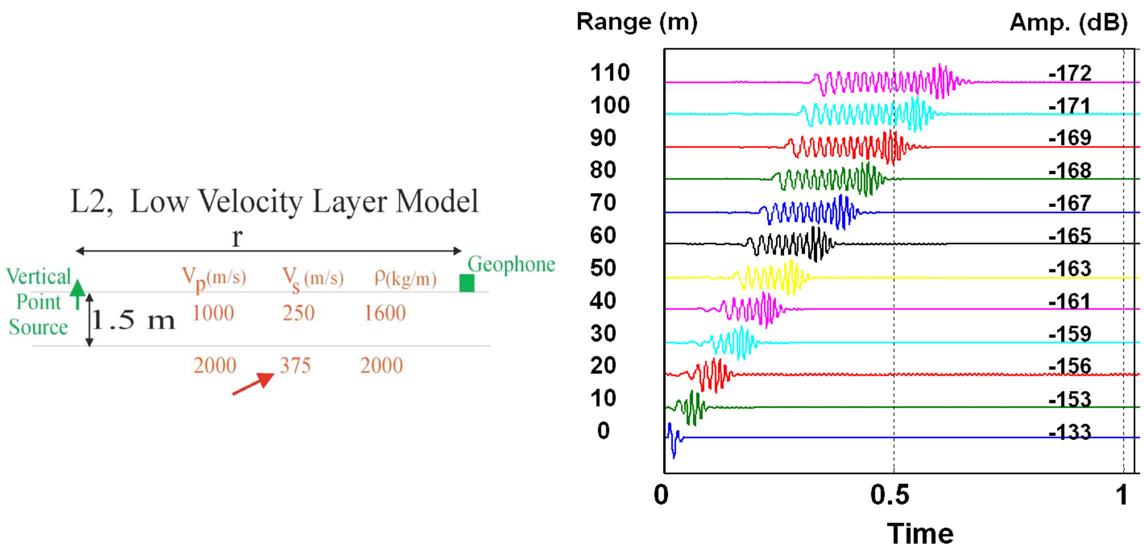

Figure 4. Waveforms at varying ranges for the L2 model. L2 model has a small velocity contrast between the layer and the halfspace. H = 1.5 m.

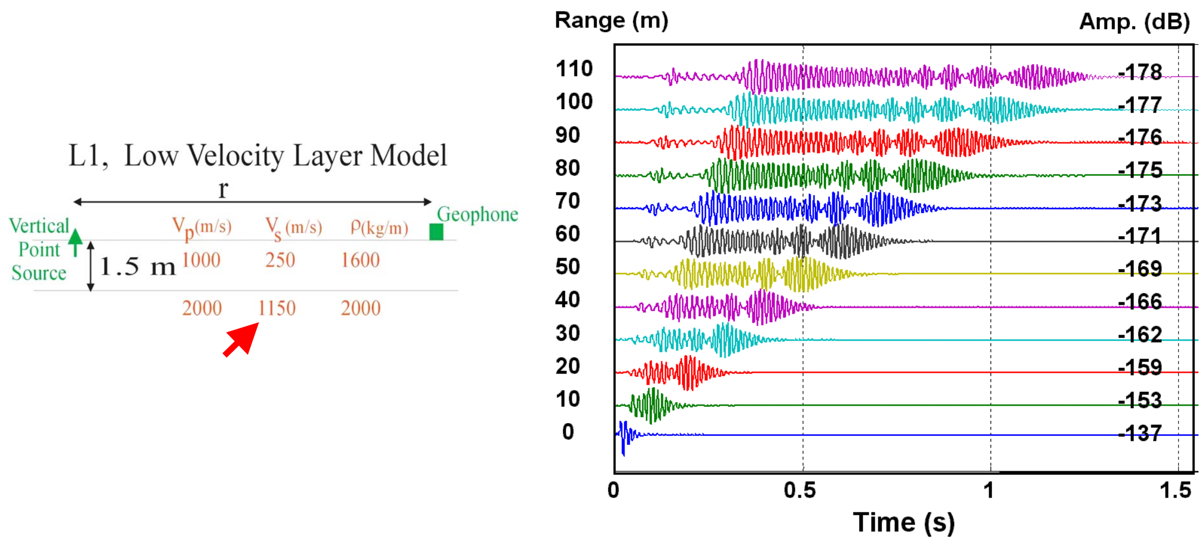

Figure 5 Waveforms at varying ranges for the L1 model. L1 model has a large velocity contrast between the layer and the halfspace. The s-wave contrast is more than a factor of four. H = 1.5 m.

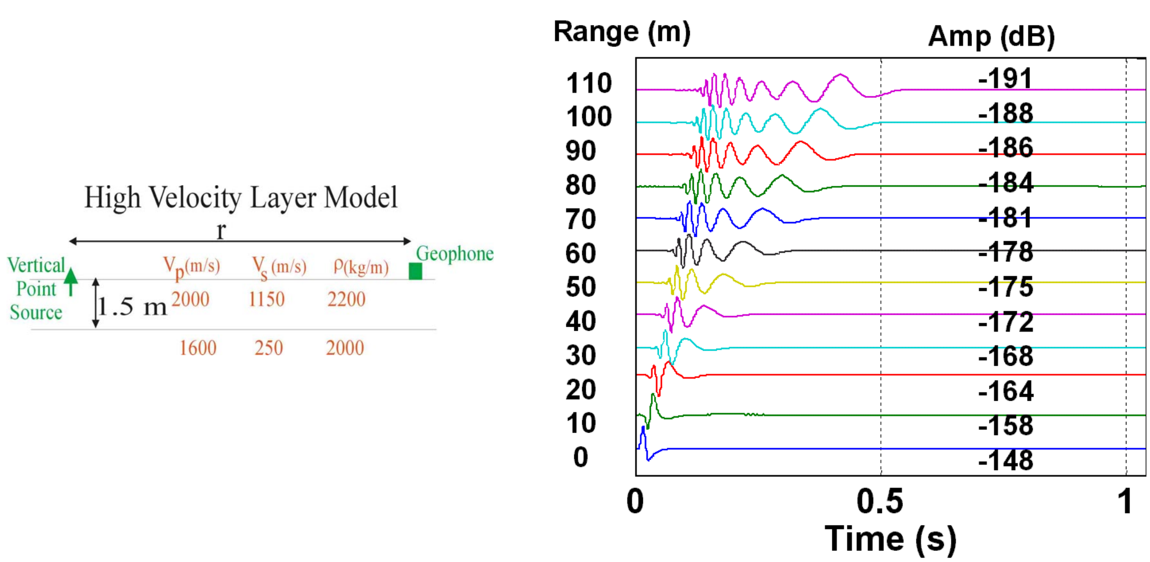

Figure 6. Waveforms at varying ranges for the H1 model. H = 1.5 m.

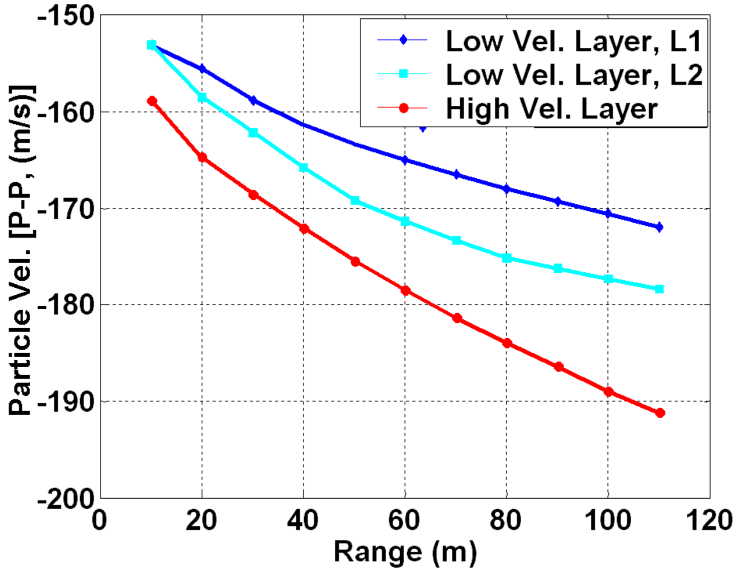

Figure 7. Amplitude versus distance for three models. H = 1.5 m.

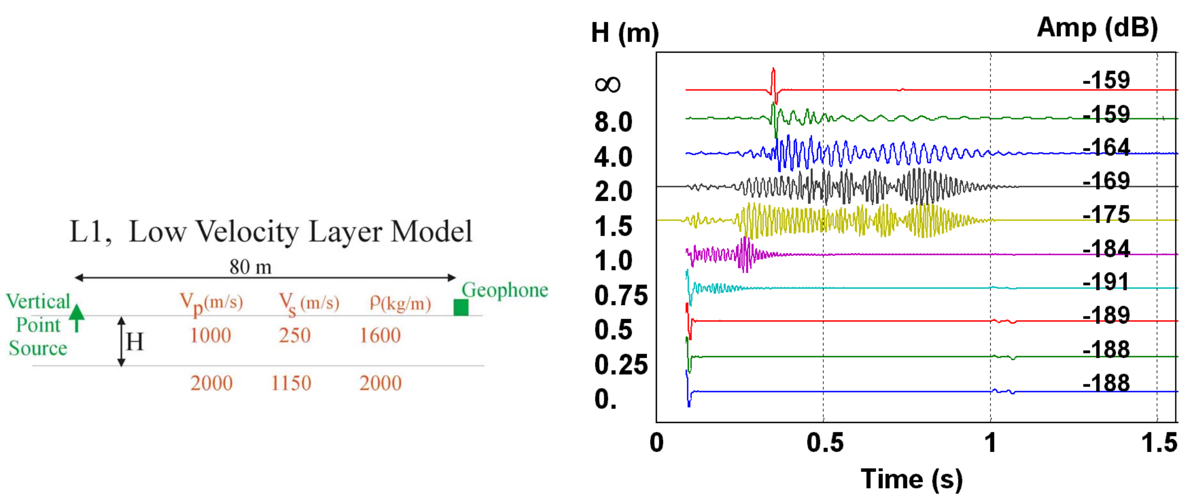

Figure 8. Waveforms for varying H, for the L1 model. H given on figure.

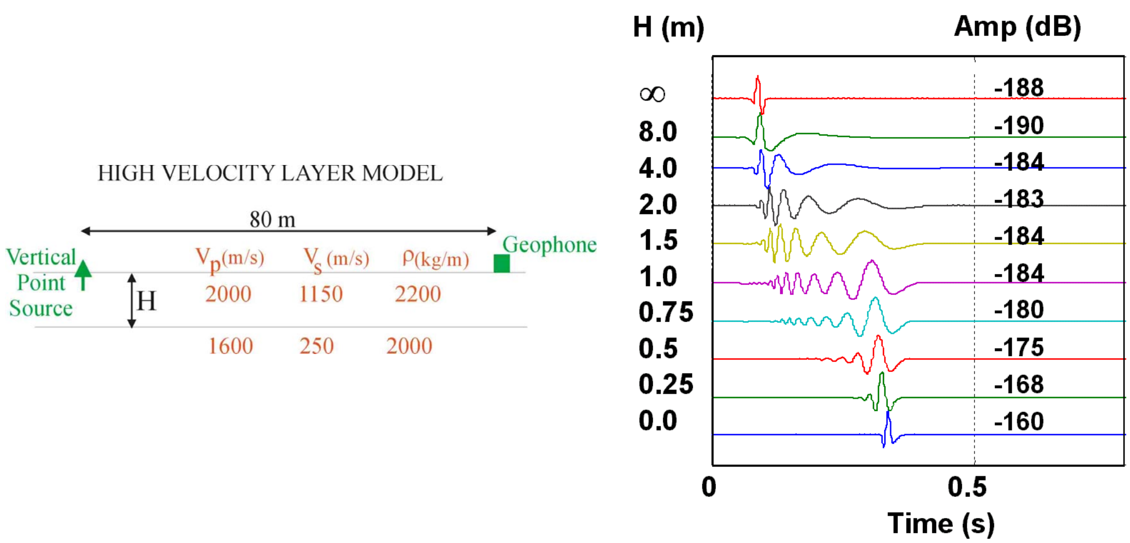

Figure 9. Waveforms for varying H, for the H1 model. H given on figure.